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PHYSICAL CHARACTERISTICS AND SOLUBILITY OF LONG-LIVED AIRBORNE PARTICULATES IN URANIUM PRODUCING AND MANUFACTURING FACILITIES

A report upon completion of PHASE I of the study

by

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PHYSICAL CHARACTERISTICS AND SOLUBILITY OF LONG-LIVED AIRBORNE PARTICULATE IN URANIUM PRODUCING AND MANUFACTURING FACILITIES-PHASE I

Experimental work carried out and report prepared by R. Robertson, S.D. Jones, and D.J. Beggs of Becquerel Laboratories Inc. under sub-contract to MacLaren Plansearch Inc. on behalf of the Atomic Energy Control Board.

ABSTRACT

The rates of dissolution in simulated lung fluid of uranium-238, thorium-230, radium-226, and lead-210 from a uranium ore matrix and of uranium-238 only from a uranium dioxide matrix have been studied in vitro. Changes in solubility rates accompanying changes in lung fluid pH and flow rate have been examined. The effect of neutron irradiation of the solid matrices upon solubility has been investigated. Using the carrier-free tracer isotopes, thorium-234, radium-224, and lead-203, the hold-back effects of coprecipitation and adsorption upon available surfaces within the dissolution cells have also been explored.

It has been found that a shift from pH 7 to pH 8 in the lung fluid phase reduces the solubility of uranium-238 by about 10%, thorium-230 by about 90%, and radium-226 by approximately 40%. There is no discernible effect upon lead-210. These results indicate the nee for very tight pH control in extraction experiments contemplated in subsequent phases of this project.

Within the range of the flow rates studied, it has been found that the solubility rates of all the elements of interest do not change significantly in moving from an approximately constant lung fluid flow rate to a flow rate decreasing with time.

Results indicate that fast neutron irradiation of a uranium ore matrix reduces the solubility rate of uranium-238 by about 50%, of thorium-230 by 20-30% and of radium-226 by 20-30%. There was no discernible effect on lead-210. Similar irradiation of a uranium dioxide matrix appeared to have no effect on uranium-238 solubility. The integrated fast neutron flux was approximately 5×10^{14} neutrons per centimetre squared in both cases. The irradiation was by reactor neutrons under cadmium and represents the irradiation conditions typically used for the determination of uranium and thorium on aerosol filters by neutron activation analysis. This effect of reduction in solubility deserves further investigation.

Tracer studies showed that coprecipitation and adsorption effects play a prominent role in determining the rates of extraction of thorium and lead from the extraction cells used in this work. The effect for radium is small. Uranium was not included in the tracer studies.

RÉSUMÉ

Les taux de dissolution, dans un liquide pulmonaire simulé, d'uranium 238, de thorium 230, de radium 226 et de plomb 210 provenant d'une matrice de minerai d'uranium, et d'uranium 238 seulement provenant d'une matrice de dioxyde d'uranium, ont été étudiés in vitro. Les changements des taux de solubilité accompagnant des changements de pH et de débit du liquide pulmonaire ont été examinés. L'effet de l'irradiation neutronique des matrices solides sur la solubilité a été examiné. Les effets de rétention de la coprécipitation et de l'adsorption sur les surfaces accessibles dans les cellules de dissolution ont aussi été explorés au moyen de thorium 234, de radium 224 et de plomb 203, isotopes marqueurs sans vecteur.

On a constaté qu'un changement de pH de 7 à 8 dans le liquide pulmonaire diminue la solubilité de l'uranium 238 de 10 % environ, du thorium 230 de 90 % environ et du radium 226 de 40 % environ. Aucun effet n'est décelable pour le plomb 210. Ces résultats indiquent qu'il faudra contrôler le pH très étroitement dans les expériences d'extraction prévues dans les prochaines étapes de ce projet.

Dans la gamme des débits étudiés, on a trouvé que les taux de solubilité de tous les éléments d'intérêt ne varient pas beaucoup lorsqu'on passe d'un débit de liquide pulmonaire presque constant à un débit décroissant dans le temps.

Les résultats indiquent qu'une irradiation par des neutrons rapide d'une matrice de minerai d'uranium diminue le taux de solubilité de l'uranium 238 d'environ 50 %, du thorium 230 d'environ 20 à 30 % et du radium 226 de 20 à 30 %. Aucun effet n'est discernable pour le plomb 210. Une irradiation similaire d'une matrice de dioxyde d'uranium a semblé n'avoir aucun effet sur la solubilité de l'uranium 238. Le flux intégré de neutrons rapides était d'environ 5×10^{14} neutrons par centimètre carré dans les deux cas. L'irradiation a été réalisée avec des neutrons de réacteur à cadmium dans les conditions habituellement utilisées pour doser l'uranium et le thorium dans les filtres à aérosol par analyse par activation neutronique. L'effet de baisse de solubilité méritent une recherche plus poussée.

Les études de marquage ont révélé que les effets de la coprécipitation et de l'adsorption jouent un rôle déterminant dans l'évaluation des taux d'extraction du thorium et du plomb contenus dans les cellules d'extraction utilisées dans le présent travail. L'effet est peu important dans le cas du radium. L'uranium n'a pas été étudié.

DISCLAIMER

The Atomic Energy Control Board is not responsible for the accuracy of the statements made or opinions expressed in this publication and neither the Board nor the authors assume liability with respect to any damage or loss incurred as a result of the use made of the information contained in this publication.

TABLE OF CONTENTS

ABSTRACT	i
DISCLAIMER	ii
A. INTRODUCTION	1
B. SAMPLES PROCESSED	1
C. EXTRACTION EQUIPMENT AND PROCEDURES	2
D. SUMMARY OF RESULTS AND DISCUSSION	2
1. pH Effects	2
2. Solubility Mechanisms	2
3. Flow Rate Effects	3
4. Radiochemical Analysis	3
E. CLOSING REMARKS AND RECOMMENDATIONS	4
F. FIGURES AND TABLES	4
REFERENCES	22

A. INTRODUCTION

The Atomic Energy Control Board has undertaken to carry out a broad study of the in vitro lung fluid solubility behaviour of workplace aerosols of radiological health concern in the Canadian uranium industry. The radionuclides of interest are uranium-238, thorium-230, radium-226, and lead-210. The work will be carried out in 5 phases over a period of 3 years.

A summary of the results of Phase I of the work are presented here. The intent of Phase I was to provide data concerning the effects upon solubility of certain experimental parameters. The questions concerning these parameters arose from a prior feasibility study and needed clarification before the main study could begin. The effects studied in Phase I were: the sensitivity of solubility rate with regard to lung fluid pH changes within the range pH7 to pH8; the roles of coprecipitation and adsorption and their influence upon solubility measurements; the importance of lung fluid flow rate and its relationship to possible solubility saturation effects; and the effect of fast neutron irradiation upon solubilities.

The summarised results of the experimental studies of these effects are presented in Section D of this report. The data indicate a possible need for further experimentation before the commencement of Phase II. The analytical results in detail will be laid out in appendices to the final report presented when all five phases of this project are complete.

B. SAMPLES PROCESSED

Two sorts of sample materials were subjected to extraction experiments in this work. The first was a uranium ore, the CANMET* certified reference material BL-5. This material is essentially a low-grade concentrate from Beaverlodge, Saskatchewan. It has certified values for uranium 7.09%, for radium-226 857 Bq/g and for lead-210 866 Bq/g. Separate analysis by Becquerel Laboratories Inc. for thorium-234 and thorium-230 yielded values in the 860-870 Bq/g range indicating that a state of secular equilibrium exists for the uranium series in this material. The physical form of BL-5 is a powder of -200 mesh, ie. less than 75 micron.

The second material used in extraction processes was unsintered uranium dioxide commercially produced by the fluid bed process. The physical form of this material was a powder of -400 mesh, ie. less than 38 micron.

A third material, uranium ore from the Elliot Lake region of Ontario, was used as a substrate in the experiments on

* Canada Centre for Mineral and Energy Technology

coprecipitation and adsorption involving the tracers thorium-234, radium-224, and lead-203. This material was preferred over the higher specific activity ore BL-5 whose high thorium-234 concentration was undesirable because of possible background contribution. The physical form of the Elliot Lake ore was a powder of -200 mesh, ie. less than 75 micron.

C. EXTRACTION EQUIPMENT AND PROCEDURES

The extraction equipment and procedures used are very similar to those described in reference 1 and identical to those described in reference 2. A schematic outline of the equipment is shown in Figure 1. The reader is referred to references 1 and 2 for further details.

D. SUMMARY OF RESULTS AND DISCUSSION

1. pH Effects

Solubility data were derived for the uranium ore BL-5 and for uranium dioxide at nominal pH's 7 and 8. In the pH 7 work, the simulated lung fluid was held in the range pH 6.8-7.2 and for the pH 8 work, in the range pH 7.8-8.2. The experimental results are summarised in Tables 1-5. Lung fluid fraction volumes ranged from 400-800 mL.

All of the radionuclides of interest except lead-210 show decreasing solubility with increasing lung fluid pH. The effect for uranium-238 is 9% for BL-5 and 16% for uranium dioxide. The effects for thorium-230, and radium-226 in BL-5 are 87% and 41% respectively. Lead-210 showed no effect.

It is evident from these data that pH needs to be tightly controlled in real extraction experiments, especially in those cases where thorium radionuclides are of interest. In previous work, pH was held in the range 7.2-7.6. This current work indicates a need for monitoring and control within the range 7.3-7.5.

2. Solubility Mechanisms

It was recognised in the feasibility study and associated discussions that coprecipitation and adsorption might hold back dissolved elements and therefore influence solubility data as derived in extraction experiments similar to these described here. The results presented in Tables 6 and 7 confirm these thoughts. Since aerosol material within a lung is much more widely dispersed than in the in vitro experimental situation, and since the lung does not present similar adsorption surfaces, it can be argued that the solubility estimates through the in vitro method used here will tend to err on the low side.

3. Flow Rate Effects

For practical reasons it is desirable to have an experimental situation where flow rate decreases with time. There is a strong tendency anyway for flow rate to decrease as filters become obstructed with particulates. Maintaining a high and constant flow rate under these conditions is difficult. Another good practical reason for preferring decreasing flow rate is the requirement for longer sampling periods as an experiment proceeds. The sampling periods required in Phases II-V of this project vary from 0.25 days for first fractions collected to 32 days for last fractions collected. Under constant flow rate conditions the volumes of the last fraction would be 128 times the volume of the first fraction. Last fractions might therefore need to be several tens of litres in volume.

For the above reasons, and bearing in mind that solubility rates decrease quite sharply with extraction time thereby alleviating concerns about solution saturation, it was decided to compare solubility data for approximately constant and decreasing flow rates. The results are presented in Tables 8-11. Flow rate for the constant flow rate extractions was approximately 400mL per fraction. For the decreasing flow rate extractions, volumes per fraction varied from approximately 800mL for the first fraction collected to 400mL for the last fraction. There is no trend in the data which would rule out using for this current project the decreasing flow rate approach which has been used in previous studies.

4. Radiochemical Analysis

Instrumental neutron activation analysis (INAA) has been proposed as a method of analysis for uranium on aerosol filters to be subjected to solubility studies. Before the INAA method can be used, however, it needs to be shown that prior neutron irradiation of samples does not affect solubility.

The data presented in Tables 12-16 indicate that fast neutron irradiation of the uranium ore BL-5 under conditions typically applied in the analysis of aerosol filters for uranium suppresses the solubility of uranium-238 by about 50%, thorium-230 by 20-30%, and of radium by 20-30%. There was no discernible effect on lead-210. The extraction of uranium-238 from uranium dioxide appears to be unaffected by similar neutron irradiation. Both ore and uranium dioxide samples received an integrated fast neutron flux of 5 x 10^14 neutrons per centimetre squared. The irradiation was carried out by reactor neutrons with the samples encapsulated under cadmium.

The results are surprising. It was expected that neutron damage might enhance rather than suppress solubility. The consequences regarding the use of INAA for non-destructive determinations of

uranium on filters are obvious.

E. CLOSING REMARKS AND RECOMMENDATIONS

The work carried out in PHASE I can be judged worthwhile in the sense that several questions which needed to be answered have been answered. Not in all cases, however, are the answers favourable to progress and costs.

The necessity of tight pH control imposes an experimental constraint which will increase project costs. It is recommended that automated pH monitoring and control be installed on the equipment to be used for future extraction work.

With regard to solubility mechanisms, it can be said that the adsorption and coprecipitation effects are much larger than desirable and will negatively influence observed solubility rates. Without substantial overhaul of the experimental design, little can be done about these effects and users of the results will have to be content with estimates of solubility conservative relative to the real lung situation.

The questions regarding constant vs. decreasing flow rate have been substantially answered. It would be useful, however, to determine just how low flow rates can be before saturation effects show themselves.

The effect of neutron irradiation on solubility is surprising and disappointing. A non-destructive means of measuring uranium on filters is essential and other methods such as X-ray fluorescence analysis or direct gamma-ray counting may not be as suitable as INAA. It is recommended that the neutron irradiation effect be re-investigated in a further experiment in order to confirm or otherwise the observed results.

F. FIGURES AND TABLES

Figure 1 is shown on page 5. Tables 1-16 appear on pages 6-21.

F. FIGURES AND TABLES

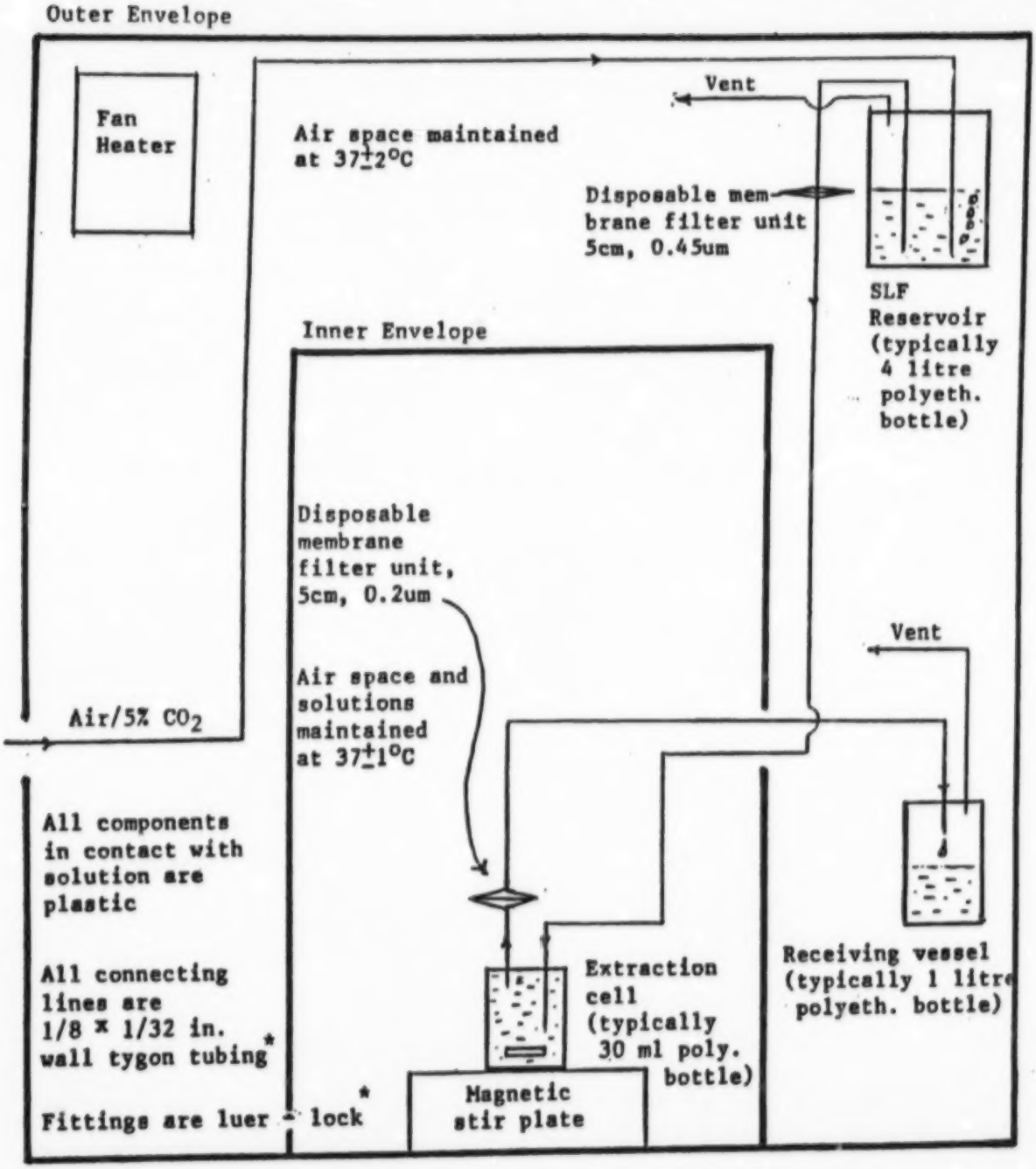
Outer Envelope
Fan Heater
Air space maintained at 37±2°C
Vent
Disposable membrane filter unit 5cm, 0.45um
SLF Reservoir (typically 4 litre polyeth. bottle)
Inner Envelope
Disposable membrane filter unit, 5cm, 0.2um
Air space and solutions maintained at 37±1°C
Vent
Air/5% CO_2
All components in contact with solution are plastic
All connecting lines are 1/8 x 1/32 in. wall tygon tubing *
Fittings are luer lock *
Extraction cell (typically 30 ml poly. bottle)
Magnetic stir plate
Receiving vessel (typically 1 litre polyeth. bottle)

FIGURE 1: Schematic Representation of Extraction Equipment

* Except between the extraction cell and the downstream membrane filter. These components were connected with 1/4 in. tygon tubing and plastic hose fittings to avoid blockage with glass fibres.

Table 1: EXPERIMENT No. 1, pH EFFECTS URANIUM-238

Four parallel extractions of uranium-238 from the standard uranium ore BL-5

Lung Fluid Fraction (hours)	Uranium-238 Extracted (ug)			
	Extraction Cell #1 pH 7, 50mg BL-5	Extraction Cell #2 pH 7, 51mg BL-5	Extraction Cell #3 pH 8, 49mg BL-5	Extraction Cell #4 pH 8, 50mg BL-5
1. 0-24	320	330	250	250
2. 24-48	125	130	154	220
3. 48-72	121	116	111	106
4. 72-120	141	144	115	84
Total Extracted	707	720	630	660
Mean of Totals Extracted (expressed in percent)	pH 7, 19.9%		pH 8, 18.4%	

Table 2: EXPERIMENT No. 2, pH EFFECTS URANIUM-238

Four parallel extractions of uranium-238 from uranium dioxide

Lung Fluid Fraction (hours)	Uranium-238 Extracted (ug)			
	Extraction Cell #1 pH 7, 65mg UO_2	Extraction Cell #2 pH 7, 62mg UO_2	Extraction Cell #3 pH 8, 48mg UO_2	Extraction Cell #4 pH 8, 44mg UO_2
1. 0-24	310	340	210	190
2. 24-48	7.9	10.9	5.7	5.5
3. 48-72	3.8	6.0	1.9	3.5
4. 72-120	5.7	9.7	3.9	2.5
Total Extracted	327	367	222	202
Mean of Totals Extracted (expressed in percent)	pH 7, 0.62%		pH 8, 0.52%	

Table 3: EXPERIMENT No. 1, pH EFFECTS THORIUM-230

Four parallel extractions of thorium-230 from the standard uranium ore BL-5

Lung Fluid Fraction (hours)	Thorium-230 Extracted (Bq)			
	Extraction Cell #1 pH 7, 50mg BL-5	Extraction Cell #2 pH 7, 51mg BL-5	Extraction Cell #3 pH 8, 49mg BL-5	Extraction Cell #4 pH 8, 50mg BL-5
1. 0-24	0.79	0.65	0.060	0.124
2. 24-48	0.31	0.27	0.051	0.071
3. 48-72	0.45	0.49	0.050	0.061
4. 72-120	0.34	0.35	0.037	0.021
Total Extracted	1.89	1.76	0.198	0.277
Mean of Totals Extracted (expressed in percent)	pH 7, 4.2%		pH 8, 0.55%	

Table 4: EXPERIMENT No. 1, pH EFFECTS RADIUM-226

Four parallel extractions of radium-226 from the standard uranium ore BL-5

Lung Fluid Fraction (hours)	Radium-226 Extracted (Bq)			
	Extraction Cell #1 pH 7, 50mg BL-5	Extraction Cell #2 pH 7, 51mg BL-5	Extraction Cell #3 pH 8, 49mg BL-5	Extraction Cell #4 pH 8, 50mg BL-5
1. 0-24	1.78	2.58	1.17	1.13
2. 24-48	0.97	0.64	0.43	1.29
3. 48-72	0.63	0.68	0.48	0.30
4. 72-120	1.40	1.32	0.66	0.33
Total Extracted	4.78	5.22	2.74	3.05
Mean of Totals Extracted (expressed in percent)	pH 7, 11.4%		pH 8, 6.7%	

Table 5: EXPERIMENT No. 1, pH EFFECTS LEAD-210

Four parallel extractions of lead-210 from the standard uranium ore BL-5

Lung Fluid Fraction (hours)	Lead-210 Extracted (Bq)			
	Extraction Cell #1 pH 7, 50mg BL-5	Extraction Cell #2 pH 7, 51mg BL-5	Extraction Cell #3 pH 8, 49mg BL-5	Extraction Cell #4 pH 8, 50mg BL-5
1. 0-24	0.98	0.86	0.75	0.87
2. 24-48	0.96	0.61	0.98	1.10
3. 48-72	0.65	0.28	0.58	0.48
4. 72-120	0.90	0.77	0.68	0.64
Total Extracted	3.48	2.52	2.99	3.09
Mean of Totals Extracted (expressed in percent)	pH 7, 6.8%		pH 8, 7.1%	

Table 6: EXPERIMENT No. 5, SOLUBILITY MECHANISMS

Recovery of injected thorium, radium, and lead tracers. Extraction cells 1 and 2 contained a Whatman 2.4cm 934-AH glass microfibre filter. Cells 3 and 4 contained 50mg of crushed uranium ore from the Elliot Lake area.

The table gives the percentage of each tracer recovered in each of 2 fractions of simulated lung fluid collected from each extraction cell. Fraction volumes ranged from 95 to 168mL ie. about 3-5 extraction cell volumes. The extraction cells and contents were conditioned under flow for 24 hours prior to tracer injection.

		% Tracer Recovered			
Tracer	Fraction	Extraction Cell #1 Glass Fibre	Extraction Cell #2 Glass Fibre	Extraction Cell #3 Ore	Extraction Cell #4 Ore
Pb-203	1. 0-4h *	52	52	11	8
	2. 4-16h	17	20	8	10
	Total Recovered	69%	72%	19%	18%
Ra-224	1. 0-4h	96	87	78	77
	2. 4-16h	11	14	13	17
	Total Recovered	107%	101%	91%	94%
Th-234	1. 0-4h	57	56	52	58
	2. 4-16h	6	7	6	5
	Total Recovered	63%	63%	58%	63%

* Time 0 is the time tracers were injected.

Table 7: EXPERIMENT No. 6, SOLUBILITY MECHANISMS

Recovery of injected thorium, radium, and lead tracers. Extraction cells 1 and 2 contained a Whatman 2.4cm 934-AH glass microfibre filter. Cells 3 and 4 contained 50mg of crushed uranium ore from the Elliot Lake area.

The table gives the percentage of each tracer recovered in each of 4 lung fluid fractions collected from each extraction cell. Fraction volumes were in the range 150 to 225mL ie. 4-6 extraction cell volumes. The table also gives the percentage of each tracer recovered from the in-cell solids, the in-cell solution and from the cell walls at the end of the extractions.

		% Tracer Recovered			
Tracer	Fraction	Extraction Cell #1 Glass Fibre	Extraction Cell #2 Glass Fibre	Extraction Cell #3 Ore	Extraction Cell #4 Ore
Pb-203	1. 0-24h *	4.0	3.6	7.3	7.4
	2. 24-64h	3.2	2.2	3.5	3.4
	3. 64-96h	4.4	3.8	6.1	7.2
	4. 96-120h	11	6.7	6.6	4.9
	cell solids	12	2.9	21	23
	cell liquid	3.6	25	14	34
	cell walls	58	51	31	24
	Total Recovered	96%	95%	90%	104%
Ra-224	1. 0-24h	84	87	79	94
	2. 26-64h	1.6	4.5	4.4	3.8
	3. 64-96h	1.4	6.5	7.7	4.1
	4. 96-120h	4.3	2.3	1.2	1.8
	cell solids	2.4	< 1	3.4	2.3
	cell liquid	1.7	< 1	2.2	5.4
	cell walls	4.0	< 1	4.8	< 1
	Total Recovered	99%	100%	103%	111%
Th-234	1. 0-24h	15	7.0	27	28
	2. 24-64h	< 1	< 1	< 1	< 1
	3. 64-96h	< 1	1.6	3.5	3.1
	4. 96-120h	1.3	1.0	1.2	1.5
	cell solids	18	32	30	25
	cell liquid	1.8	9.4	9.3	18
	cell walls	62	28	28	32
	Total Recovered	98%	79%	99%	108%

* Time 0 is the time tracers were injected.

Table 8: EXPERIMENT Nos. 3 and 4, FLOW RATE EFFECTS URANIUM-238

Two sets of two parallel extractions of uranium-238 from the standard uranium ore BL-5.

Lung Fluid Fraction (hours)	Uranium-238 Extracted (ug)			
	Expt. #3 Cell #1 Constant Flow 56mg BL-5	Expt. #4 Cell #1 Constant Flow 62mg BL-5	Expt. #3 Cell #2 Decreasing Flow 65mg BL-5	Expt. #4 Cell #2 Decreasing Flow 54mg BL-5
1. 0-24	200	340	380	410
2. 24-48	192	320	187	230
3. 48-72	127	124	138	83
4. 72-96	97	58	85	66
5. 96-154	124	147	96	142
6. 154-202	73	230	52	161
Total Extracted	813	1219	938	1092
Mean of Totals Extracted (expressed in percent)	Constant Flow 24.1%		Decreasing Flow 24.5%	

Table 9: EXPERIMENT Nos. 3 and 4, FLOW RATE EFFECTS THORIUM-230

Two sets of two parallel extractions of thorium-230 from the standard uranium ore BL-5.

Lung Fluid Fraction (hours)	Thorium-230 Extracted (Bq)			
	Expt. #3 Cell #1 Constant Flow 56mg BL-5	Expt. #4 Cell #1 Constant Flow 62mg BL-5	Expt. #3 Cell #2 Decreasing Flow 65mg BL-5	Expt. #4 Cell #2 Decreasing Flow 54mg BL-5
1. 0-24	0.10	0.77	0.59	0.79
2. 24-48	0.044	0.48	0.22	0.30
3. 48-72	0.12	0.41	0.18	0.33
4. 72-96	0.084	0.26	0.10	0.24
5. 96-154	0.070	0.27	0.076	0.18
6. 154-202	0.067	0.18	0.033	0.11
Total Extracted	0.49	2.37	1.20	1.95
Mean of Totals Extracted (expressed in percent)	Constant Flow 2.7%		Decreasing Flow 3.2%	

Table 10: **EXPERIMENT Nos. 3 and 4, FLOW RATE EFFECTS RADIUM-226**

Two sets of two parallel extractions of radium-226 from the standard uranium ore BL-5.

Lung Fluid Fraction (hours)	Radium-226 Extracted (Bq)			
	Expt. #3 Cell #1 Constant Flow 56mg BL-5	Expt. #4 Cell #1 Constant Flow 62mg BL-5	Expt. #3 Cell #2 Decreasing Flow 65mg BL-5	Expt. #4 Cell #2 Decreasing Flow 54mg BL-5
1. 0-24	1.51	4.25	1.42	3.77
2. 24-48	0.88	1.69	0.99	2.27
3. 48-72	1.10	1.10	0.65	0.74
4. 72-96	0.71	0.52	0.69	0.34
5. 96-154	0.55	0.99	0.91	0.87
6. 154-202	0.32	1.91	0.47	1.21
Total Extracted	5.07	10.50	5.13	9.20
Mean of Totals Extracted (expressed in percent)	Constant Flow 15.2%		Decreasing Flow 14.6%	

Table 11: EXPERIMENT Nos. 3 and 4, FLOW RATE EFFECTS LEAD-210

Two sets of two parallel extractions of lead-210 from the standard uranium ore BL-5.

Lung Fluid Fraction (hours)	Lead-210 Extracted (Bq)			
	Expt. #3 Cell #1 Constant Flow 56mg BL-5	Expt. #4 Cell #1 Constant Flow 62mg BL-5	Expt. #3 Cell #2 Decreasing Flow 65mg BL-5	Expt. #4 Cell #2 Decreasing Flow 54mg BL-5
1. 0-24	0.89	1.35	1.03	1.46
2. 24-48	0.73	0.67	0.71	0.91
3. 48-72	0.49	0.67	0.37	0.60
4. 72-96	0.48	0.40	0.17	0.72
5. 96-154	0.71	0.18	0.12	0.64
6. 154-202	0.49	1.42	0.24	0.73
Total Extracted	3.79	4.69	2.62	5.05
Mean of Totals Extracted (expressed in percent)	Constant Flow 8.28%		Decreasing Flow 7.73%	

Table 12: EXPERIMENT No. 7, EFFECT OF NEUTRON IRRADIATION, URANIUM-238

Two parallel extractions of uranium-238 from neutron irradiated uranium ore BL-5.

Uranium-238 Extracted (ug)

Lung Fluid Fraction (hours)	Extraction Cell #1 56mg BL-5	Extraction Cell #2 52mg BL-5
1. 0-24	240	181
2. 24-48	92	55
3. 48-72	36	41
4. 72-96	33	34
5. 96-154	30	59
6. 154-202	53	61
Total Extracted	484	431
Total Extracted (expressed in percent)	12.2%	11.7%

Note: Values in this table are to be compared with columns 4 and 5 in Table 8 which give equivalent data for non-irradiated material.

Table 13: EXPERIMENT No. 7, EFFECT OF NEUTRON IRRADIATION, URANIUM-238

Two parallel extractions of uranium-238 from neutron irradiated uranium dioxide.

Uranium-238 Extracted (ug)

Lung Fluid Fraction (hours)	Extraction Cell #3 52mg UO_2	Extraction Cell #4 51mg UO_2
1. 0-24	210	260
2. 24-48	5.2	6.0
3. 48-72	3.5	3.2
4. 72-120	7.1	6.6
Total Extracted	226	276
Total Extracted (expressed in percent)	0.49%	0.61%

Note: Values in this table are to be compared with the values in Table 2 where comparable data for non-irradiated material are given.

Table 14: EXPERIMENT No. 7, EFFECT OF NEUTRON IRRADIATION, THORIUM-230

Two parallel extractions of thorium-230 from neutron irradiated uranium ore BL-5.

Thorium-230 Extracted (Bq)

Lung Fluid Fraction (hours)	Extraction Cell #1 56mg BL-5	Extraction Cell #2 52mg BL-5
1. 0-24	0.31	0.29
2. 24-48	0.17	0.25
3. 48-72	0.08	0.10
4. 72-96	0.07	0.15
5. 96-154	0.07	0.14
6. 154-202	0.15	0.18
Total Extracted	0.85	1.11
Total Extracted (expressed in percent)	1.8%	2.5%

Note: Values in this table are to be compared with columns 4 and 5 in Table 9 which give equivalent data for non-irradiated material.

Table 15: EXPERIMENT No. 7, EFFECT OF NEUTRON IRRADIATION, RADIUM-226

Two parallel extractions of radium-226 from neutron irradiated uranium ore BL-5.

Radium-226 Extracted (Bq)

Lung Fluid Fraction (hours)	Extraction Cell #1 56mg BL-5	Extraction Cell #2 52mg BL-5
1. 0-24	1.52	2.62
2. 24-48	1.15	1.12
3. 48-72	0.57	0.84
4. 72-96	0.41	0.16
5. 96-154	0.45	0.16
6. 154-202	0.26	0.19
Total Extracted	4.36	5.09
Total Extracted (expressed in percent)	9.1%	11.4%

Note: Values in this table are to be compared with columns 4 and 5 in Table 10 which give equivalent data for non-irradiated material.

Table 16: EXPERIMENT No. 7, EFFECT OF NEUTRON IRRADIATION, LEAD-210

Two parallel extractions of lead-210 from neutron irradiated uranium ore BL-5.

Lead-210 Extracted (Bq)

Lung Fluid Fraction (hours)	Extraction Cell #1 56mg BL-5	Extraction Cell #2 52mg BL-5
1. 0-24	1.04	0.95
2. 24-48	1.06	0.63
3. 48-72	0.72	0.40
4. 72-96	0.59	0.29
5. 96-154	0.87	0.23
6. 154-202	0.50	0.57
Total Extracted	3.83	3.05
Total Extracted (expressed in percent)	7.9%	6.8%

Note: Values in this table are to be compared with columns 4 and 5 in Table 11 which give equivalent data for non-irradiated material.

REFERENCES

1. Robertson, R. Feasibility Study of the Dissolution Rates of Uranium Ore Dust, Uranium Concentrates and Uranium Compounds in Simulated Lung Fluid, AECB Report no. 205, 1986 July.

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